but always so constricted at the mouth as to admit only disjointed bones, deprived of their flesh. In these are encountered human remains, unfortunately, however, so reduced to powder that it is impossible to determine the physical characters of the race.

In conclusion, I can safely affirm, that even to-day it is very hard to find on the Amazonas proofs of greater industry than that furnished by these mounds, or a higher appreciation of the beautiful than is manifested by the ornamentation of the pottery of the ancient inhabitants of Marajó.

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NATIVE BITUMENS AND THE PITCH LAKE OF TRINIDAD.

BY W. O. CROSBY.

MINERAL pitch and the most of the native bitumens have been known from very early times. Among the ancient writers we find many statements indicating not only a knowledge but a practical use of these substances; and it is known that asphaltum was applied to architectural purposes more than four thousand years ago. That this substance was held in high estimation may be inferred from its being ranked by these writers among the best building materials of those ages, and from its application to structures requiring great solidity and permanence.

It is mentioned at several places in the Bible under the names of *slime* and *pitch*: Noah, in building the ark, being commanded to "pitch it within and without with pitch," while we read that the bulrush ark of the infant Moses was "daubed with slime and with pitch." Herodotus says it was used as a cement in building the strong walls of Babylon, large quantities being brought down to the Euphrates by the small river Is. These fountains of Is, celebrated as having attracted the attention of Alexander the Great, Trojan and Julian, still continue to pour out inexhaustible supplies. The same author describes the mode of obtaining solid bitumen and petroleum from a spring near Anderica, on one of the Ionian islands, and of separating them from each other and from foreign substances. This spring is flowing there to-day.

Diodorus Siculus and Josephus noticed the bitumen of the Dead sea, its use in medicine and in coating ships; its importation into Egypt; and its being there used with aromatic spices for the purpose of embalming bodies, which it preserved from putrefaction.

In their structures, the Romans directed much attention to solidity and permanence, and of course endeavored to select what were considered the most useful and durable materials. That these materials were often good is shown by the state of preservation of many of their works, and by the fact that their cement is scarcely equaled by any of modern time; and yet Vitruvius, a celebrated architect of the age of Augustus, speaks of bitumen as superior to every other kind of cement, and regrets its scarcity.

Notwithstanding the long time that native bitumens have been known, it is only within the present century that they have come to be extensively employed in the arts; and that geologists and chemists have reached definite conclusions concerning their origin, modes of occurrence, properties and relations. The prevalent notion that these substances are of rare and limited occurrence is entirely erroneous, for, as I shall presently show, the bitumens, taken as a class, are very widely and abundantly diffused through the crust of the earth. They are found in every quarter of the globe, and in every geological formation from the Cambrian to the present time. Their occasional association with what appear to be igneous rocks, has led some writers to infer that in their origin they are in some way connected with volcanic action. An explanation which, as Canon Kingsley has remarked, "savors somewhat of a 'bull;' for what a volcano could do to pitch, save to burn it up into coke and gases, it is difficult to see." When, as undoubtedly sometimes happens, the bore of a volcano passes through sedimentary strata holding bitumen or bituminous coal, it is easy to see how the connection of these substances with volcanic products may arise. But be their associations what they may, it has been definitely settled that in their origin the bitumens, like the coals, are always strictly organic. In every case they are the more or less transformed tissues of plants or animals.

Under the general name of bitumen are included both the liquid forms, petroleum and naphtha, and the solid varieties such as asphalt. Chemically considered, the bitumens are hydrocarbons the average composition being represented by the general formula $C_n H_{2n}$. The so-called bituminous coals, which, however, are destitute of true bitumen, are likewise hydrocarbons. These are distinguished from the bitumens by their smaller hydrogen ratio, analysis affording the general formula $C_n H_{\frac{2n}{3}}$, and

by the important facts that unlike many of the bitumens they are not liquid at ordinary temperatures, and unlike all the solid bitumens, are incapable of assuming the liquid state on the application of heat. The coals partake in a large degree of the nature of their chief constituent element, carbon, the most thoroughly solid substance known, distinguishing, as we should, solidity from density. In their entire insolubility, again, the coals are strongly contrasted with the bitumens, the latter class being all more or less soluble in liquids like benzole, sulphide of carbon, oil of turpentine and ether; and the less fluid bitumens, as asphalt, dissolving in the more fluid, naphtha-like, varieties.

Notwithstanding the general distinctness of these two great classes of native hydrocarbons, there is a point where they are not easily separated. Among the bitumens there are different degrees of fusibility and solubility, and a concomitant variation of the hydrogen ratio, presenting a regular gradation as we pass from naphtha with the maximum solubility and fusibility, and the largest proportion of hydrogen, through petroleum, mineral tar, and the various asphalts to idrialite, which, having the composition of bituminous coal, is fusible with difficulty, and only slightly soluble. From idrialite the passage is easy to true bituminous coal, and from this, as is well known, to anthracite. So that, as Dr. T. Sterry Hunt has stated it, "Anthracite or nearly pure carbon, on the one hand, and petroleum and naphtha, or carbon with a maximum of hydrogen, on the other, represent the two extremes of a series of which bituminous coals and asphalts are intermediate terms."

Following is a list of the more important members of this series, with their formulas, which have been calculated for twenty-four equivalents of carbon, to compare with the chief constituent of wood, cellulose:

Cellulose		$C_{24}\ H_{40}\ O_{20}$
Naphtha, Petroleum		$C_{24}\ H_{50}$
Mineral Tar		$C_{24}\ H_{48}$
Asphalt	varies from	$C_{24}\ H_{44}\ O$
	to	$C_{24}\ H_{28}\ O$
Idrialite		$C_{24}\ H_{16}$
Bituminous coal	varies from	$C_{24}\ H_{20}\ O_3$
	to	$C_{24}\ H_{16}\ O$
Anthracite	varies from	$C_{24}\ H_{10}\ O$
	to	$C_{24}\ H_6\ O_{.5}$

A little study of these figures will make it clear that all these different hydrocarbons may be produced, theoretically at least, by removing from cellulose, which represents all woody matter, variable proportions of carbonic anhydride (CO_2), marsh gas (CH_4), and water (H_2O); and this is, in many cases, the course that nature pursues. Under ordinary conditions decaying wood is attacked by the oxygen of the air and burned up to carbonic anhydride, water and ashes as completely as if thrown into a furnace; but if kept out of contact with the atmosphere, as when lying beneath the water and mud of a marsh, or buried in deposits of sand or clay, the wood is still subject to decomposition, though the decay is of a very different order and much less complete. The oxygen is the most active element of the wood, and the first to leave; but it never goes alone, always taking with it some of the hydrogen in the form of water, or of carbon as carbonic anhydride. Afterwards other portions of the carbon and hydrogen unite and make their escape as the inflammable gaseous substance known as marsh gas. The presence of this gas in most swamps and marshes attests that nature's laboratory for the manufacture of coal and bitumen is still in operation. Both these species of decomposition, whether in the air or out of it, go on much more rapidly in the presence of heat; the first process being exemplified in every stove and furnace, and the second by the charcoal pit; for anthracite, the ultimate product of slow decomposition out of contact with the air, is simply a mineral charcoal.

A further inspection of our formulas will make it evident that to transform cellulose or wood into the average bitumen we must remove all the oxygen, some carbon and but little hydrogen; while for the conversion of vegetable matter into coal, the oxygen is less completely removed, and the hydrogen suffers much greater loss than the carbon. In the one case the escaping volatile products of the decomposition are mainly carbonic anhydride with some marsh gas; and in the other case the loss has occurred chiefly in the form of water, the carbon remaining largely intact. This is an important difference, and one which would be more obvious if our series included all the varieties of coal. The fact is this series is not a very natural one after all. It represents fairly well the changes resulting in the production of the different bitumens, viz: a complete abstraction of the oxygen and a gradual diminution of the hydrogen; but the coals are generated

by a gradual diminution of both elements, as the following series will show, the formulas being still computed for comparison with cellulose :

Peat and Brown coal		$C_{24}\ H_{30}\ O_{10}$
Lignite		$C_{24}\ H_{24}\ O_7$
Bituminous coal	varies from	$C_{24}\ H_{20}\ O_3$
	to	$C_{24}\ H_{16}\ O$
Anthracite	varies from	$C_{24}\ H_{10}\ O$
	to	$C_{24}\ H_6\ O_{.5}$

We are, then, to regard the coals and bitumens as forming two distinct but parallel series, in each of which there is an evident tendency to the reduction of organic matter to the state of pure carbon. Theoretically, at least, the final results, like the starting points, are chemically the same for the two series; but they are reached by different roads. Graphite, which is essentially pure carbon, is the final term of the coal series, and it is not improbable that *diamond* stands in the same relation to the bitumens, for Liebig has suggested that diamond is most probably formed by crystallization of carbon from a liquid hydrocarbon.

Oxygen and hydrogen exist in cellulose in the right proportions to form water, and the conversion of this substance into coal, as already stated, consists mainly in the union of these two elements. But we may now profitably notice some important observations of Principal Dawson, according to which we should no longer regard the ordinary vegetable fibre or cellulose composing the main body of plants as the principal source of coal, but certain epidermal tissues which differ from cellulose in being much poorer in oxygen. In other words, it is the bark mainly, and not the solid wood from which coal is formed. Dr. Hunt gives the composition of cork, which is a bark, as $C_{24}\ H_{37}\ O_7$. These cortical tissues, Dawson says, "are very little liable to decay, and resist, more than most other vegetable matters, aqueous infiltration, properties which have caused them to remain unchanged and resist the penetration of mineral substances more than other vegetable tissues. These qualities are well seen in the bark of our American white birch (*Betula alba*). It is no wonder that materials of this kind should constitute considerable portions of such vegetable accumulations as the beds of coal, and that when present in large proportion they should afford richly bituminous beds. All this agrees with the fact apparent on examina-

tion of common coal, that the greater number of its purest layers consist of the flattened bark of the sigillariæ and similar trees, just as any single flattened trunk imbedded in shale becomes a layer of pure coal. It also agrees with the fact that other layers of coal, and also the cannels and earthy coals, appear under the microscope to consist of finely comminuted particles, principally of epidermal tissues, not only of the fruits and spore cases of plants, but also of their leaves and stems."

Every one, I think, must have observed, at some time, decaying logs, or better, stumps, of which little or nothing remains but a cylinder of bark, and this is apparently little altered. Dawson has found such hollow stumps in the coal formation, with abundant evidence that they had been the homes of animals, such as insects and reptiles. Such phenomena are the best illustrations of the superior resistance which this class of vegetable tissues offers to atmospheric action, a resistance undoubtedly due to the small proportion of oxygen which they contain; their composition, as Dr. Hunt has pointed out, approaching closer to resins and fats than to wood, and, "like these substances, they repel water, with which they are not easily moistened."

We have now traced to their origin in the vegetable kingdom all of the coals, so far as known, and many of the true bitumens. The notion is rapidly gaining ground among geologists, however, that the bitumens, especially the lighter and more fluid forms, such as petroleum and naphtha, are largely of animal origin. This view, for the development of which we are mainly indebted to Dr. T. Sterry Hunt, is based upon the following general considerations: (1) Animal tissues, the average chemical composition, but not the molecular structure, of which may be represented by the formula $C_{24}\ H_{38}\ N_6\ O_4$, approaches even more nearly than epidermal vegetable tissues to the composition of bitumens. (2) Although, as a rule, eminently unstable compounds, subject, under ordinary circumstances, to rapid and complete decomposition; yet we have good reason to believe that there are vast regions where the conditions are not only favorable for, but must necessitate, that slow and partial decay resulting in the formation of bituminous substances. The regions referred to are the depths of the ocean. Recent researches have shown, contrary to the old idea, that the deep sea holds an abundant fauna. All grades of animal life, from the highest to the lowest, have need

of a constant supply of oxygen. Now on the land, vegetation is constantly returning to the air the oxygen consumed by animals, but in the abysses of the ocean vegetable life is scarce or wanting, and hence it must result that over these greater than continental areas countless myriads of animals are living habitually on short rations of oxygen, and in water well charged with carbonic anhydride, the product of animal respiration. As a consequence, when these animals die their tissues do not find the oxygen essential for their perfect decomposition, and in the course of time become buried, in a half decayed state, in the ever increasing sediments of the ocean floor. The same thing must happen to animals living in higher bathymetric zones, all the way to the surface, whose bodies sink to the bottom after death; they yield a little ammonia and carbonic anhydride, and then pass into the comparatively stable condition of a liquid or solid bitumen. During the lapse of ages these sediments, rich in organic matter, will be consolidated into limestones and slates, and at a later period may be elevated to form new land; a process which has been many times repeated in the past. (3) For, as geologists well know, rocks corresponding to those just described are of very frequent and extensive occurrence among the formations now exposed to their observation.

Petroleum is usually associated with salt, the same well often affording both oil and a strong brine; a fact very suggestive of the marine origin of the petroleum. While the disagreeable smell of some oleiferous limestones is probably due, as remarked by Newberry, to the animal origin of the oil.

The capability which the so-called bituminous coals possess of yielding, by a process known to chemists as destructive distillation, various liquid and gaseous hydrocarbons, some of which resemble petroleum, a property common to most substances of organic origin, has not only led to their being erroneously regarded as bituminiferous, but many geologists have inferred that we have here a clew to the origin of the vast reservoirs of petroleum known to exist in this and other countries, and which have of late years been tapped with such astonishing results. Anthracite is undoubtedly a species of natural coke, produced when ordinary bituminous coal loses its volatile ingredients; its general mode of occurrence and geological relations prove this. But is nature's mode of making coke strictly analogous to what

goes on in the retorts of the gas works? Probably not. We have every reason to believe that the natural process is a very gradual one, and that the volatile products are all gaseous. In every bituminous coal mine in the world the two permanent gases, carbonic anhydride and marsh gas—the deadly choke-damp and fire-damp of the miners, are constantly escaping from the coal, but unaccompanied by any oily, petroleum-like liquid. This action, sufficiently long continued, must result in the production of anthracite, and that it has so resulted is evidenced by the fact that the rocks lying above the great deposits of anthracite are quite free from the liquid bitumens we should otherwise expect to find there. The fact is, that in Pennsylvania the anthracite is in one end of the State and the petroleum in the other; and, moreover, the petroleum is obtained from a formation below the Carboniferous, to which the coal belongs. Its origin is sometimes referred to the carbonaceous shales or pyroschists of the underlying Hamilton beds; but these, like the coals, are found, on examination, not to contain any bitumen, and like the bituminous coals, they still retain perfectly the power of yielding bitumens when sufficiently heated. Beyond the limits of Pennsylvania the general facts are the same, and nowhere is there any evidence proving a connection of the petroleum with the coals or pyrochists. Petroleum is generally obtained from wells sunk in sandstone or slate. In some cases it is probably indigenous in these, but usually it has been forced up by hydrostatic pressure or sponge-like absorption from oleiferous limestones. There are several extensive formations of these limestones in Eastern North America, and geologists are only beginning to appreciate their abundance and richness. The oil is found filling the pores and cavities of fossil shells and corals, and saturating the entire substance of the limestone, the evidence being plain that it is indigenous in this position and has not been introduced into the limestone subsequent to the formation of the latter. Dr. Hunt has made a quantitative determination of the petroleum in a limestone of Niagara age occurring near Chicago, with the following almost incredible result: Although the formation has a thickness of only thirty-five feet, yet in each square mile it must contain not less than "seven and three quarter millions of barrels of petroleum." He says further, "The total produce of the great Pennsylvania oil region for the ten years from 1860 to 1870 is

estimated at twenty-eight millions of barrels of petroleum, or less than would be contained in four square miles of the oil-bearing limestone formation of Chicago."

As a rule limestone is too massive and close grained to permit the oil to flow freely through it to supply wells sunk in this rock; but overlying sandstones gradually soak up the oil, and its accumulation along the crests of anticlinal arches in the latter rock is due to the presence of water in the strata, which, being the heavier liquid, forces the oil to the top. The richest wells are those which tap large bodies of oil contained in the great fissures and cavities which, as geologists well know, usually accompany an anticlinal fold of the strata. Very often these subterranean chambers are filled partly with oil and partly with gas, and the latter serves a useful purpose in forcing the former to the surface. This gas is derived from the oil itself, and if the situation of the fissure or the texture of the rock are such that the gas can escape, its formation will continue until, in some cases at least, the petroleum is reduced to a thick viscid or even solid condition. It is by a similar but more rapid fractional distillation that the petroleum is refined for illuminating purposes, the solid residue being chiefly the substance paraffine. The fissures filled with solidified or inspissated petroleum are not wholly theoretical, for several have been discovered, which, through some accident of erosion or faulting of the strata, are now exposed on the surface. The most noted of these is in New Brunswick, the material occupying the fissure being the famous and valuable mineral, albertite. This is a jet-black lustrous substance intermediate in physical characters between bituminous coal and asphaltum, though chemically it is much nearer the latter than the former, affording the formula $C_{24} H_{32} O_{1.6}$. This deposit bears no resemblance to a true coal bed, but fills a large irregular crevice cutting across the strata. The enclosing shales are rich in the remains of fish, and so bituminous as to be visibly oily, and to "sustain a fire without the aid of other fuel." The grahamite of West Virginia is a substance closely resembling albertite and occurring in a similar fissure or crevice. The same phenomena, on a smaller scale, are many times repeated in Canada, in the vicinity of Quebec and elsewhere.

Whenever petroleum is exposed to the air for any length of time, as when it slowly exudes from the rocks, forming petroleum

springs, it is likely, in a manner similar to that just described, to lose its more volatile ingredients and become semi-solid like mineral tar, or solid like asphalt. And so it happens that many of the smaller deposits of asphaltum in this and other countries are simply dried up petroleum, and are of animal origin. The great deposits of the globe, however, those which constitute the principal source of the asphaltum employed in the arts, do not appear to have been formed in this way; but have, in most cases at least, been derived directly, after the manner of coal, as already explained, from decaying vegetation.

Extensive deposits of asphaltum, such as that for which the island of Trinidad is celebrated, are commonly regarded as something exceptional, something out of the natural order, a freak of nature. This notion is without foundation in facts, for asphaltic substances are not only widely disseminated, as already stated, but in not a few localities, which form a zone girdling the earth, they are accumulated in such vast abundance as to ensure an unfailing supply for man's purposes for all time to come.

A list of the localities where asphaltum is especially abundant may further enforce this view, these are: Cuba, several of the Windward islands, especially Trinidad and Barbadoes, the Caribbean shore of South America, particularly the province of Maracaybo, Caxitambo and Berengela in Peru, where are lakes of asphalt similar to that on Trinidad; Mexico, Texas and California in North America, Persia and Arabia, Palestine on the shores of the Dead sea and on Mount Lebanon, Ionian islands, France, Switzerland and Portugal, It is a curious fact that the asphalts are confined almost wholly to tropical and sub-tropical regions. There appears to be in low latitudes some general climatic or other condition which has in many cases determined the conversion of vegetable matter into bitumen instead of coal.

The largest deposit in Europe is probably that in the Val-de-Travers, Neufchatel, Switzerland, which has been worked for more than one hundred and fifty years. This occurs in rocks of Cretaceous age; but as a rule the great masses of asphalt are found in connection with Tertiary strata. This is the geological position in Trinidad, Barbadoes, Peru and other points in South America and in California. Trinidad is composed chiefly of Tertiary and Secondary beds, the former predominating; but toward the north the island otherwise quite low, is bordered by a bold

range of mountains, a detached link of the great littoral Cordillera of Venezuela. These are composed of ancient crystalline strata, and stand like a wall between the Tertiary plain on the south and the Caribbean sea, and the long chain of volcanic islands on the north. There is scarcely a trace of true volcanic action observable in Trinidad, the hot mud springs—the so-called mud volcanoes —hardly coming in that category. They may be classed as hydro-thermal but not as igneous phenomena. I have also seen little or no evidence of volcanic action during the past epochs in the history of the island; and the frequent severe earthquake shocks of the regions on the west and north are very rarely felt with destructive force in this favored isle.

Asphaltum, usually accompanied by mineral tar and petroleum, occurs at many points on Trinidad and also on the adjacent main. But the largest and most interesting deposit, not only of this region but of the world, is that known as the Pitch Lake. This is on Point La Brea (La Brea being Spanish for *the pitch*), in the south-western part of the island, and one mile from the Gulf of Paria. The topography of the country about the lake is extremely simple; from three sides—north, west and south—the land slopes gradually upward from the sea to the surface of the lake, which lies one hundred and thirty-eight feet above the gulf; while on the east the land is slightly higher than the lake. In other words, the Pitch Lake is on the faintly-marked shoulder of a broad, low ridge which, projecting into the gulf of Paria, forms the peninsula or promontory of La Brea. Contrary to all topographic laws and precedents, this so-called lake is not in a valley, but on a hill-top. I have already denied the existence, both past and present, of volcanic phenomena in this region, and yet the situation of this remarkable deposit of asphalt is very much as if the broad-mouthed crater of a low-lying volcano were filled to the brim with this material. I say filled to the brim, because on the three sides named above, the surface of the pitch is even with the brow of the hill, and more so, for at many points the viscous substance is constantly overflowing and moving seaward, after the manner of very sluggish lava streams. The motion is extremely slow, the pitch, where it issues from the lake, being a brittle solid. The moving masses present curved lines and surfaces, which are convex downwards; and Kingsley has very aptly likened these streams of asphalt to glaciers, the lake representing a *mer de*

glace. The asphalt becomes harder the longer it is exposed to the air and the sun, through loss of its volatile ingredients, and consequently the downward progress of the "black glaciers" must sooner or later be checked, if not entirely stopped. It seems impossible to determine the extent of the overflow, for although the entire slope from the lake to the sea appears as a continuous stratum of pitch, the soil being everywhere very thin or entirely wanting, yet it is probable, as pointed out by Messrs. Wall and Sawkins,[1] that the most of this superficial sheet has exuded from the asphaltic sandstone—a sandrock supersaturated with asphaltum—which forms the rocky basis of that portion of the ridge where the free asphalt is found. The area covered or underlaid by this mantle of pitch is estimated at 3000 acres.

The bitumen is certainly not injurious to plant life, for the scanty soil covering the pitch, and consisting largely of that material in a pulverulent state, supports a luxuriant vegetation. The village of La Brea, on the shore, with the boiling houses where the asphalt is refined, rests on the pitch; and the inhabitants complain that their houses are liable to be thrown out of level by the rising or sinking of the tarry foundations. It seems as if everything superficial here, vegetation, houses, roads, etc., must be slowly but surely drifting toward the sea.

"It is fortunate," as one writer has remarked, "that the pitch when compact will not kindle, or in other words will not burn without a wick, for otherwise the entire region, including the village, might suffer the fate of Sodom and Gomorrah."

The pitch not only forms the sea-shore for the greater part of a distance of four miles, but in front of the village it appears from beneath the sea as a solid barrier reef some hundred yards from the shore, which is a source of danger to unwary boatmen when the water is rough. It is probable that this peninsula of La Brea owes its existence to the protection afforded the land by the asphalt, which resists the action of the waves and running water far better than the unconsolidated clays and sands forming the coast to the north and south.

We may now return to the fountain head, the lake. Of the various published descriptions of this remarkable phenomenon, there are very few that can justly lay any claim to accuracy, and strange to say these are not to be found in encyclopedias, nor even in our best text books of science. Probably no object in

[1] Report on the Geology of Trinidad.

nature has been so grossly misrepresented as the Pitch Lake of Trinidad. In an official history of the English Exposition of 1851, under the head of descriptions of articles from Trinidad, it is stated that, "The Pitch Lake is on the highest land in the island. It is soft and fluid at the center, and there is an active submarine volcano near the coast." I have already given the true altitude of the lake as one hundred and forty feet, while the highest point on the island is Mt. Tucutche, 3100 feet above the sea. The submarine volcano is a petroleum spring which comes up under the water a short distance from shore; the water is visibly oily over an area of several rods, and bubbles of gas are sometimes seen to escape, but nothing farther, though another writer speaks of this as "a submarine volcano which at times makes a noise like thunder and emits naphtha and petroleum." The lake itself is usually described as three miles in circumference, hot and fluid in the center, but cold and solid toward the shore. In point of fact this body of pitch, which is of approximately circular outline, is scarcely one and one-half miles in circuit, and there is no part of its surface that may not be walked upon with impunity. The temperature is uniform throughout. The area of the lake is ninety-nine acres. Its surface, soft enough in a few spots to receive the impression of a man's boot, is for the most part quite hard and firm, and everywhere of a dull earthy-brown or brownish-black color. The fracture is eminently conchoidal, but the lustre is always dull, the result of an admixture of twenty to thirty per cent. of earthy matter, sand and clay. These impurities are removed by boiling, and the pitch then becomes shining black and still more brittle.

There are some twenty or more patches on the lake, five to fifteen yards in diameter where soil has collected and vegetation —trees, shrubs and grasses—has gained a foothold, forming green islands or oases. The surface presents many small dome-shaped swellings or protuberances, from an inch to a foot in diameter; these pitch bubbles are always hollow, and contain traces of the lighter portions of vegetation in a half decayed state, the thin covering appearing to have been raised by gases given off from the decomposing leaves and twigs, or liberated by the sun's heat from the pitch itself. Excavations made in the pitch show that below the surface these cavities or vesicles are exceedingly numerous; they are usually almond-shaped or ellipsoidal, being

flattened by pressure, and though always the result of gaseous expansion, are commonly filled with water; in fact the entire mass of the pitch is saturated with water, so that even where quite soft it will not soil the hands, because the water oozes out and prevents adhesion. The earthy impurities of the pitch also assist in rendering untrue, in this instance, the old proverb that one cannot touch pitch without being defiled.

The pitch is mined or quarried by excavating areas thirty or forty feet square to a depth of two to four feet. As soon as the work ceases on one of these cellar-like excavations the surrounding asphalt, seeking to restore the equilibrium, begins to obliterate it, the walls not closing in perceptibly but the bottom rising up, and in a few days no trace of the opening remains. This is only one of many indications of greater fluidity below the surface. The plasticity of the pitch is evidently due to the oily matter which it contains, and not in any sensible degree to the temperature. Hardened bitumen, it is true, may be fused by the application of sufficient heat, but that which is naturally fluid remains so at all ordinary temperatures. As already explained, when the asphalt is exposed to the air it becomes solid through loss of its volatile ingredients. Towards the center of the lake are several detached areas, a rod or two in breadth, which are softer than the rest of the surface, and yield under the feet, "so that on standing a few minutes one feels that he is gradually settling down, and in the course of ten or fifteen minutes he may find himself ankle deep." "But," as Mr. Manross[1] truly says, "in no place is it possible to form those bowl-like depressions round the observer described by former travelers." Nor is it probable that Kingsley is right in saying, "No doubt there are spots where, if a man stayed long enough, he would be slowly and horribly engulfed." The inferior density of the human body would prevent its submergence even if the pitch were quite fluid.

In the vicinity of these places many small streams of gas escape from the pitch. The evil smell and the deposit of sulphur left on the pitch tell us that the gas is chiefly sulphuretted hydrogen; but the sulphurous odor ceases to be perceptible at a distance of a few rods, and does not extend for ten or twelve miles, as some writers have asserted.

The surface of the lake does not present a continuous sheet of asphalt, but is traversed by a net-work of channels in which the

[1] American Journal of Science, 1855.

rain-water collects. These anastomose and divide most curiously, forming one connected system, and dividing the pitch into numerous flat-topped or slightly convex areas or islands which are usually of quite irregular outline, though sometimes nearly circular, and from ten to one hundred feet in diameter. A piece of marbled paper would make an excellent map of the lake. The sides of the channels are always convex, presenting curves of great regularity and beauty; and where three or four channels meet, a star-shaped depression is formed. Canon Kingsley[1] says, "Conceive a crowd of mushrooms, of all shapes, from ten to fifty feet across, close together side by side, their tops being kept at exactly the same level, their rounded rims squeezed tight against each other; then conceive water poured on them so as to fill the parting seams. Thus would each mushroom represent, tolerably well, one of the innumerable flat asphalt bosses which seem to have sprung up, each from a separate center, while the parting seams would be of much the same shape as those in the asphalt, broad and shallow atop, and rolling downward in a smooth curve till they are, at bottom, mere cracks from two to ten feet deep. Whether these cracks actually close up below and the two contiguous masses of pitch become one, cannot be seen. As far as the eye goes down they are two, though pressed close to each other," the hard exteriors of the masses preventing them from coalescing.

The water filling the channels is clear, pure rainwater, and contains numbers of small fishes, water beetles and other aquatic animals. It has been observed escaping from the canals at eight nearly equidistant points on the circumference of the lake.

Several hypotheses have been proposed to account for the peculiar structure of the lake. Mr. Manross says, "The channels are produced and maintained by the following singular process: Each of the many hundred areas into which the lake is divided possesses an independent revolving motion in this wise: In the center of the area the pitch is constantly rising up *en masse*, displacing that which previously occupied the center, and forcing it towards the circumference. The surface becomes covered with concentric wrinkles and the interior structure somewhat laminated. Where the edge of such an expanding area meets that of the adjoining one the pitch rolls under to be thrown up again in the center at some future period. It is difficult to conceive of a

[1] At Last: A Christmas in the West Indies.

motion like this going on in a material almost of stony hardness, but that such a revolution is constantly taking place over the entire surface of this black lake cannot be doubted. The conclusion then to which a close observation leads us in regard to the present condition of this singular lake is, not that it has suddenly cooled down from a boiling state as heretofore described, but that solid as the material is, it is still boiling, although with an indefinitely slow motion. As the descent of the glaciers may be considered the slowest instance of flowing in nature, so the revolutions of the scarcely less solid bitumen of this lake may be set down as the slowest example of ebullition."

Messrs. Wall and Sawkins, on the contrary, deny the existence of the revolving motion, and consider that each of the areas represents a center of emission where the asphalt has issued from the underlying sandstone, "and gradually advanced until the material from the surrounding foci being encountered, further progression was impeded, and the accumulation proceeded in the vertical in place of the horizontal direction." But the present level of the lake has evidently been maintained for ages, and consequently it is difficult to see why, if this view is correct, the asphaltic bosses have not flattened out and closed up the water channels.

Neither of these views can be regarded as entirely satisfactory. Mr. Manross is undoubtedly right as regards the circulation, though in error as to its cause. He finds unique and conclusive evidence of the revolving process in "numerous pieces of wood which being involved in the pitch are constantly coming to the surface. They are often several feet in length and five or six inches in diameter. On reaching the surface they generally assume an upright position, one end being detained in the pitch while the other is elevated by the lifting of the middle. They may be seen at frequent intervals all over the lake, standing up to the height of two or even three feet. They look like stumps of trees protruding through the pitch, but their *parvenu* character is curiously betrayed by a ragged cap of pitch which invariably covers the top and hangs down like hounds' ears on either side." These fragments of wood are of the same recent origin as the leaves and twigs contained in the vesicles of the pitch. From the surrounding forest or the green islands of the lake itself, they have found their way into the water channels,

become water-logged, sunk to the bottom and been drawn down by the ever-revolving pitch.

In one case at least within my observation, a recently detached portion of one of the islands of vegetation afforded incontestable evidence of a horizontal movement of the subjacent pitch to the extent of several feet.

According to the present writer, the true cause of the revolving motion of the pitch, and of the structure resulting therefrom, is found in a fact pointed out by Wall and Sawkins, but not insisted upon or fully appreciated by them, viz: the great diurnal range in the temperature of the surface of the pitch. On unclouded days the asphalt attains an average temperature of about 140° Fahr., and sinks during the night to 70° or 60°, suffering a variation of 70° to 80°, which must produce a considerable change of volume, especially if we consider the vesicular nature of the pitch and the quantity of water which it contains. This expansion will be superficial, and its chief tendency to extend the pitch horizontally. Where the pitch is covered by water it will not experience this alteration of volume. The courses of the water channels may have been determined originally by slight inequalities of the surface, holding shallow sheets of water, or drifting sand may have occupied these positions and served to protect the asphalt along these lines from the heat of the sun. The main point is that the protected areas would be forced downwards by the expansion of the unprotected areas, and this motion once established would continue without interruption until the contours of the present surface were developed.

Nocturnal radiation and consequent contraction could not undo the effect of the diurnal expansion, but the equilibrium would be and doubtless is maintained by the elevation of pitch from below in the center of the areas. The plastic pitch beneath the solid crust is sometimes forced upwards through the crevices in the bottom of the channels. One interesting example of this is described by Mr. Manross: "In one of the star-shaped pools of water, some five feet deep, a column of pitch had been forced perpendicularly up from the bottom. On reaching the surface of the water it had expanded into a sort of center-table about four feet in diameter, but without touching the sides of the pool. The stem was about a foot in diameter. I leaped out upon this table and found that it not only sustained my weight but the elasticity of the stem enabled me to rock it from side to side. Pieces torn

from the edge of this table sank readily, showing that it had been raised by pressure and not by its buoyancy."

No soundings have ever been made in this lake and its depth is unknown. The thickness of the deposit is of course a factor of the first importance in determining whether the supply of asphalt from this locality is likely to prove practically inexhaustible in view of the steadily increasing demand for this material in the arts. According to Wall and Sawkins each foot in depth is equivalent to 158,400 tons, and they assume the maximum average depth at thirty feet, making the total supply 4,752,000 tons. Judging by the uniformity of the asphalt and the size of the revolving areas, the true mean depth must considerably exceed this estimate. It is believed that the pitch could be readily excavated to a depth of ten or fifteen feet, and from that level iron bars could probably be forced to the bottom and the true depth accurately ascertained. In considering the question of the probable permanence of the supply, it is important to remember that the material is doubtless still escaping from the underlying asphaltic sandstone, though perhaps very slowly.

As regards its origin, the lake is believed not to differ essentially from any of the patches of pitch scattered over the surrounding country except in this, that the form of the surface has been more favorable for its accumulation. It appears to be simply a large puddle of pitch, which has oozed out of the sandstone and collected in a basin-like depression in that rock.

The observations of Mr. Wall have placed the vegetable origin of this bitumen beyond question. The asphaltic sandrock is rich in vegetable remains, and it is possible to trace every step in the conversion of these into asphaltum, until the organic texture of the wood is entirely obliterated and pure bitumen results, the external form of the wood alone remaining.

The fact that the Island of Trinidad lies between a portion of the delta of the Orinoco and the sea, long ago led Sir Charles Lyell to adopt the view that the asphalt deposits of Trinidad, including the Pitch Lake, which is on the side of the Island towards the delta, represented the drift wood brought down by the Orinoco in past geological ages. But I believe he afterwards concluded that this explanation, like the wood itself, was rather far-fetched. For it can be proved that at the time (Miocene period) when these asphaltic beds were forming, the mouth of the Orinoco was some one hundred and fifty or two hundred miles further up stream than at present.